

Advanced Satellite-Derived Wind Observations, Assimilation, and Targeting Strategies during TCS-08 for Developing Improved Operational Analysis and Prediction of Western Pacific Tropical Cyclones

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LONG-TERM GOALS

Forecasts of tropical cyclone (TC) formation and intensity change in the north-western Pacific basin are often lacking in skill, in part due to the paucity of conventional oceanic observations that are assimilated into the operational models. This lack of observations has also constrained our understanding of how TC formation is governed by environmental processes. Recently, remotely-sensed observations from satellites have become a routine and important input to the global data assimilation systems. These data can provide critical environmental data for the testing of hypotheses of TC formation and development, and improving our understanding of how environmental influences on TC structure evolve up to landfall or extratropical transition. In particular, winds derived from geostationary satellites have been shown to be an important component of the observing system in reducing TC model track forecasts. However, in regards to TC formation, intensity change, and extratropical transition, it is clear that a dedicated research effort is needed to optimize the satellite data processing strategies, assimilation, and applications to better understand the behavior of the near-storm environmental flow fields during these evolutionary TC stages. To our knowledge, this project represents the first time anyone has tried to evaluate the impact of targeted *satellite* data on TC forecasts using an automated dynamic targeted observing strategy. TCS-08 afforded us the opportunity to employ specially-processed satellite data along with observations collected in situ by the NAVY P-3, and other platforms, to investigate these objectives as they apply in the western north Pacific TC basin. The development of successful real-time strategies to optimally assimilate wind data from

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satellites will ultimately lead to the provision of improved initial and boundary conditions for the Navy's envisioned mesoscale coupled ocean-wave-atmosphere forecast model.

OBJECTIVES

The ultimate objective of this project is the development and refinement of a capability to supplement the contemporary atmospheric observation network with advanced satellite wind observations to improve high-resolution operational analyses and medium-range forecasts of western North Pacific typhoons.

One primary research goal is to evaluate and diagnose the impact of assimilating the advanced satellite wind observations on global Navy model forecasts, and high-resolution forecasts of structure change. We aim to better understand how to utilize the satellite wind data in the context of numerical model assimilation and forecast impact. Optimizing the assimilation of the experimental satellite winds will involve a continued investigation of the satellite data impacts with respect to objective targeting of analysis-sensitive regions, and utilizing 4DVAR approaches.

APPROACH

During the field phase of TCS-08, experimental satellite-derived wind observations were produced by UW-CIMSS using state-of-the-art automated methods. Hourly datasets were routinely derived from operational images provided from the Japan Meteorological Agency (JMA) MTSAT geostationary satellite. In addition, special rapid-scan (r/s) images from MTSAT-2 were provided by JMA for extended periods (24-48hrs) over specific regions, and including parts of selected typhoon life cycles. UW-CIMSS also processed these images into wind fields (higher resolution). These special satellite-derived wind observations complemented those data collected by the NRL P-3 aircraft during TCS-08, by providing unique time-continuous environmental data in locations that were deemed important to tropical cyclone formation and development.

The project uses the latest versions of the NRL Atmospheric Variational Data Assimilation System – Accelerated Representer (NAVDAS-AR) and NOGAPS, the Navy's current operational data assimilation and global forecast model systems, so that the research results may be easily transitioned to improve the Navy's operational predictions. We expect that the NAVDAS 4DVAR assimilation will provide an improved analysis, since its temporal continuity better exploits the asynoptic satellite winds than 3DVAR, in which the observations are assimilated at discrete 6-hour intervals. Upon completion of the experiments, the resulting global analyses and forecasts will be made available to investigators involved in developing and testing the Navy's coupled ocean-wave-atmosphere model.

Existing adaptive observing strategies such as the Ensemble Transform Kalman Filter (ETKF) and NOGAPS Singular Vectors have been used to identify regions in which numerical forecasts are most likely to benefit from the assimilation of additional satellite wind data. A new 'synthetic observation ensemble' is being devised to answer this question more directly. Via the observation sensitivity method (for forecasts up to 24h) and data denial in the Navy forecast system (for forecasts up to 5 days), the impact of assimilating targeted high-density (hourly and rapid-scan) satellite winds on global model forecasts of tropical cyclone track and high-resolution forecasts of tropical cyclone structure is being evaluated and analyzed.

Finally, a method to diagnose the effects of modifying the wind analysis on forecasts of tropical cyclone track has been designed. This framework, designed using the Weather Research and Forecasting (WRF) model, can be extended for use in the COAMPS-TC framework at the Naval Research Laboratory, Monterey, and can be used to diagnose the effects of environmental perturbations on tropical cyclone intensity and structure.

WORK COMPLETED

In Year 5, the UW-CIMSS team collaborated with scientists at NRL-MRY to finish up data impact studies using the specially processed AMV datasets (hourly and special rapid-scan) produced from MTSAT by CIMSS, as described in previous reports. A series of experiments to quantify the impact of the MTSAT AMVs during TCS-08 have been performed at NRL Monterey using the operational version of the NAVDAS-AR, which is a full 4-dimensional variational (4d-Var) algorithm solved in observation space with a weak constraint formulation that allows the inclusion of model error. It uses asynoptic, continuous, and single-level data more effectively than the earlier 3d-Var NAVDAS system. AMVs in NAVDAS-AR are assimilated using a “super-ob” pre-processing approach that combines raw wind observations into averages within 1° latitude-longitude prisms in 50 hPa layers. It is the super-ob increments that are then actually assimilated into NAVDAS.

Our impact studies have concluded that the hourly AMVs, enhanced with the rapid-scan AMVs when available, contribute to a significant improvement in the NOGAPS forecasts of Western North Pacific tropical cyclones during the TCS-08 period. These findings have been published in a refereed journal (Berger et al., 2011), and have also resulted in operational implementation of hourly AMVs into the FNMOC NAVDAS system. Further experiments suggest that a reformulation of the synthetic tropical cyclone observation scheme in NOGAPS may lead to improved forecasts as more in-situ and remote observations become available, but the synthetic observations still appear to provide value at the current model resolution (Reynolds et al, submitted to Mon. Wea. Rev.).

Pursuant to the study objective on determining the potential for targeted enhanced AMVs for the purpose of optimizing TC forecasts through the use of several objective targeting guidance measures, it was necessary to determine what physical mechanisms these guidance measures focus on in a TC forecast. Guidance products focusing on physical mechanisms exclusive to TC steering, for example, may not be suitable for an adaptive observing system designed for improvement of TC intensity or genesis forecasting. To date, little research has been performed to uncover the physical processes in the model that these disparate guidance systems focus on.

A case study was performed involving four west Pacific typhoons from the TCS-08 experiment (Nuri, Hagupit, Sinlaku, and Jangmi). Three guidance products were produced for each case: Singular Vector (SV) guidance using the Navy Operational Global Atmospheric Prediction System (NOGAPS) model, the Adjoint-Derived Sensitivity Steering Vector (ADSSV) also using the NOGAPS model, and the Ensemble Transform Kalman Filter (ETKF) Signal Variance produced using the European Center for Medium-Range Weather Forecasts (ECMWF) 50-member ensemble courtesy of the THORPEX Interactive Grand Global Ensemble (TIGGE). Similarities and differences between target regions using these three products were investigated by use of perturbation experiments wherein prescribed vorticity perturbations were inserted into the initial conditions of the NOGAPS model, and the resulting perturbed forecast was compared to the unperturbed forecast to determine the practical impact.

RESULTS

1) Model Impact Studies

The preliminary results from the UW-NRL investigations were presented in the last annual report. In summary, for NOGAPS forecasts of length exceeding 3 days, the average error of the tropical cyclone track forecasts is reduced considerably due to the assimilation of the hourly AMVs. The same forecasts were also improved further by the inclusion of rapid-scan winds. For example, for 4-day forecasts, the average track error was reduced by ~30% when hourly winds were included, and by ~45% when both hourly and rapid-scan winds were included. Furthermore, the number of forecasts of very large error, which may be considered “busts”, was reduced by the assimilation of AMVs and the average forecast error was reduced further when a lower weight was given to the bogus vortex used in the operational NOGAPS system (Berger et al. 2011).

Six additional experiments have been conducted using the NOGAPS/NAVDAS-AR data assimilation and forecasting system to examine the impact of Atlantic and Pacific dropwindsondes, CIMSS enhanced AMVs, and increased assigned synthetic observation errors on TC track forecasts during the August-September 2008 T-PARC/TCS-08 period (Reynolds et al. 2012). The largest average reduction in track error (up to 18%) due to the enhanced AMVs is found in the eastern North Pacific, with reductions of up to 11% in both the Atlantic and western North Pacific basins. The dropwindsondes show a more consistent positive impact in the Atlantic (up to an 11% reduction) than in the North Pacific (up to 8%), and have a small impact on eastern North Pacific storms through the global propagation of the impact of dropwindsondes taken in other basins. The impact of the enhanced satellite winds and dropwindsondes are highly storm dependent. Case studies for Typhoon Jangmi and Typhoon Nuri indicate that while the additional data improved the Jangmi forecasts somewhat, it failed to improve the Nuri forecasts, on average. Synoptic evaluation of the case studies indicates that the forecast errors for both storms are impacted by the erroneous weakening of the subtropical anticyclone in the western North Pacific during the forecast integration. Examination of the full two month period indicates that this low height bias is a persistent feature. The assimilation of the enhanced AMVs systematically raises the analyzed heights in the western North Pacific, counteracting this bias. However, the impact of the additional data diminishes rapidly during the first few days of forecast integration. This bias does not increase linearly with forecast time. Rather it appears that the forecasts move quickly to a preferred climatological state, and the additional data does little to mitigate this. However, it does appear that the impact of the enhanced AMVs lasts further into the integration during the Jangmi period than during the Nuri period. This is consistent with the fact that the assimilation of the additional data improves the Jangmi forecasts, but has little impact on the Nuri forecasts.

Another set of experiments are performed by Reynolds et. al 2012 in which the error assigned to the synthetic TC observations (bogus vortex) is increased (Table 1). The synthetic observations are currently assigned very small observation error (comparable to radiosondes) in the Navy system in order to have the analyses draw closely to them. In one example, the observation errors are moderately increased (80%), such that the synthetic observations are considered less accurate than dropwindsondes, but still more accurate than AMVs.

Table 1: Description of update cycle and forecast experiments.

Experiment Name	CIMSS hourly AMVs	Dropwindsondes	Assigned synthetic observation error
NO_ADD	Not assimilated	Not assimilated	Control value
CAMV	Assimilated	Not assimilated	Control value
DROP	Not assimilated	Assimilated	Control value
CAMV_DROP	Assimilated	Assimilated	Control value
SYNTH1	Assimilated	Assimilated	Increased by 80%

To illustrate the impact of the synthetic observations relative to dropwindsondes and enhanced AMVs, Fig. 1 shows the difference in 850-hPa vorticity between the CAMV_DROP experiment, and the NO_ADD (upper left), CAMV (upper right), DROP (lower left) and SYNTH1 (lower right) experiments at a selected analysis time of 00Z 25 September during TC Jangmi. The 850-hPa vorticity is also shown for each of the experiments in red, and for CAMV_DROP in all four panels, in black. The differences introduced through dropwindsondes (upper right) are somewhat localized to the storm, although they extend 10 degrees outward from the storm center to the east and west, well beyond the immediate vicinity of the dropwindsonde locations (indicated by black dots). Because of the cyclic nature of the data assimilation system, the differences between CAMV_DROP and CAMV are due not just to the dropwindsondes in the current assimilation cycle, but represent cumulative impacts from dropwindsondes used in previous update cycles. The differences due to the CIMSS enhanced AMVs (bottom left) cover a broader area due to the wide spatial coverage of this additional data (Berger et al. 2011). Because the AMVs are based on both cloud and water vapor features, their impact extends into the relatively cloud-free region of the subtropical high. The difference due to dropwindsondes and CIMSS enhanced AMVs (upper left) occur both locally and remotely, as expected. The differences due to moderately increasing the synthetic observation assigned error variance (lower right) are localized near the storm, and are about half the magnitude of the differences introduced through the dropwindsondes.

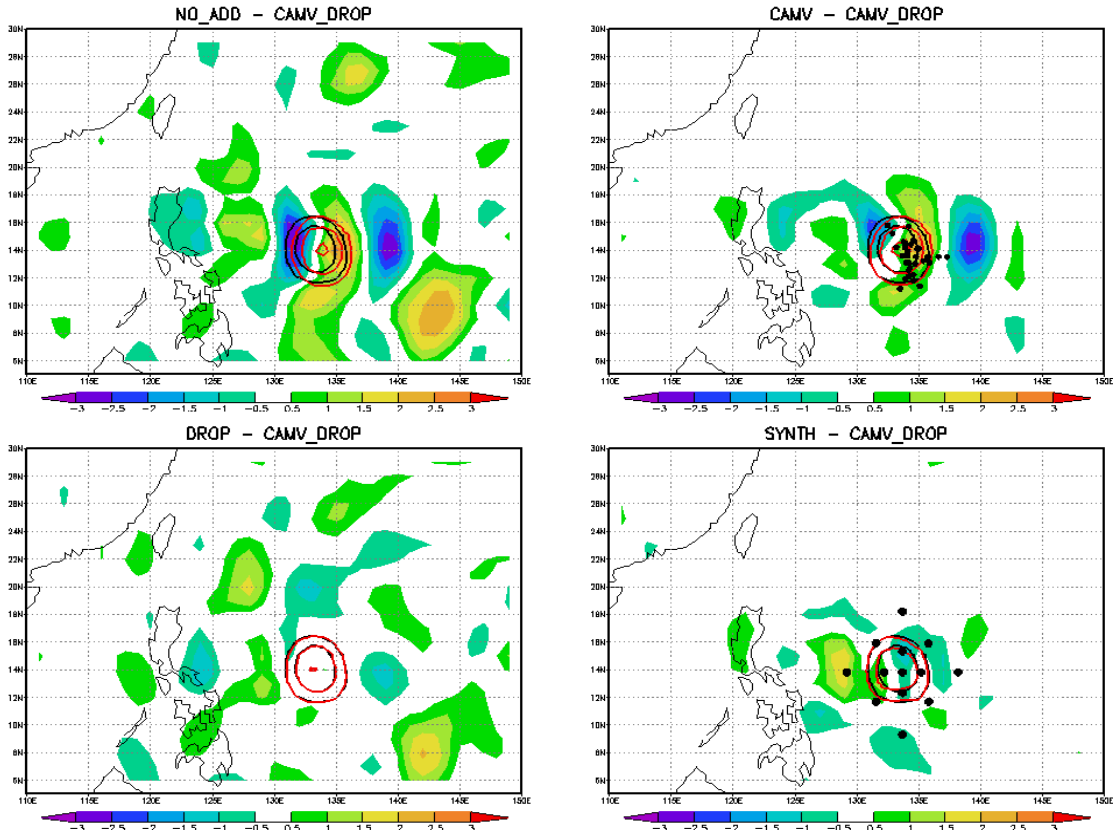


Figure 1: 850-hPa vorticity (black contours, every $5 \times 10^{-5} \text{ m s}^{-2}$, and positive values only) for the CAMV_DROP analyses shown in all four panels at the analysis time of 00Z 25 September. 850-hPa vorticity (red contours) shown for N0_ADD (upper left), CAMV (upper right), DROP (lower left) and SYNTH1 (lower right). The 850-hPa vorticity differences (shaded, interval of $0.5 \times 10^{-5} \text{ m s}^{-2}$) between CAMV_DROP and N0_ADD (upper left), CAMV (upper right), DROP (lower left) and SYNTH1 (lower right) are also shown. The locations of the dropwindsondes (synthetic observations) are indicated by black dots in the upper (lower) right panel.

The moderate increase in the assigned synthetic observation error improves forecast tracks in the eastern North Pacific at all forecast lead times, and in the western North Pacific for lead times greater than 60h. In the Atlantic the results are mixed. When the assigned errors are increased such that the synthetic observations are given very little weight, forecasts in the eastern Pacific improve further, while forecasts in the western North Pacific degrade, and the results for the Atlantic are still mixed. These results suggest that the current system may draw too closely to synthetic observations as compared to remote and in-situ observations. However, they also suggest that the synthetic observations still provide some value, particularly in the western North Pacific where forecasts degrade when the synthetics are given very little weight. Additional work that is in-progress uses adjoint methods to tune the observation error statistics for AMVs and other observations. Some preliminary results are described in a paper by Daescu and Langland, 2012.

These findings also illustrate how model biases may limit the potential improvements available through the assimilation of additional observations, and how this impact may vary substantially from storm to storm. The cause of this bias has not been established, but work is ongoing at NRL toward improving several aspects of the model formulation, including numerics, physical parameterizations, and increased horizontal resolution. The NOGAPS operational model resolution was increased to T319 in May 2010. In addition, the number of raw hourly AMVs available for assimilation has approximately doubled since 2008. The results obtained by increasing the assigned synthetic observation errors suggest that the formulation of the synthetic observations should be revisited as model resolution is increased and as more remote and in-situ observations are assimilated.

2. Analysis of TC Targeting Guidance

A case study was performed involving four west Pacific typhoons from the TCS-08 experiment (Nuri, Hagupit, Sinlaku, and Jangmi). Three guidance products were produced for each case: Singular Vector (SV) guidance using the Navy Operational Global Atmospheric Prediction System (NOGAPS) model, the Adjoint-Derived Sensitivity Steering Vector (ADSSV) also using the NOGAPS model, and the Ensemble Transform Kalman Filter (ETKF) Signal Variance produced using the European Center for Medium-Range Weather Forecasts (ECMWF) 50-member ensemble courtesy of the THORPEX Interactive Grand Global Ensemble (TIGGE). Similarities and differences between target regions using these three products were investigated by use of perturbation experiments wherein prescribed vorticity perturbations were inserted into the initial conditions of the NOGAPS model, and the resulting perturbed forecast was compared to the unperturbed forecast to determine the practical impact.

Fig. 2 shows a high degree of similarity can be seen between SV and ADSSV guidance, indicating that a perturbation to the initial conditions of the model could be prescribed so as to project strongly onto both. This indicates that the same perturbation could excite the metric used to define the SV (perturbation energy in a $15^\circ \times 15^\circ$ box centered on the position of the TC in the unperturbed 48 hour forecast) and the ADSSV (mean perturbation flow in the same sub-domain). The SV/ADSSV maximum to the southeast of Typhoon Jangmi is an example of a location where a perturbation to initial condition vorticity could easily project onto both products (Fig. 2a,b). An explanation is sought as to why a perturbation in this region can so easily excite both of these metrics.

A perturbation experiment is carried out whereby the vorticity in the model initial conditions is perturbed in this southeast region, and the model is integrated 48 hours to observe the effect on perturbation energy (SV) and mean perturbation flow (ADSSV) on the sub-domain region of interest (Fig. 3). The perturbation is constrained by the ADSSV so as to achieve a northward (southward) change in perturbation flow as a result of a positive (negative) initial condition vorticity perturbation. Both a positive and a negative perturbation are introduced separately to observe the effect on the TC.

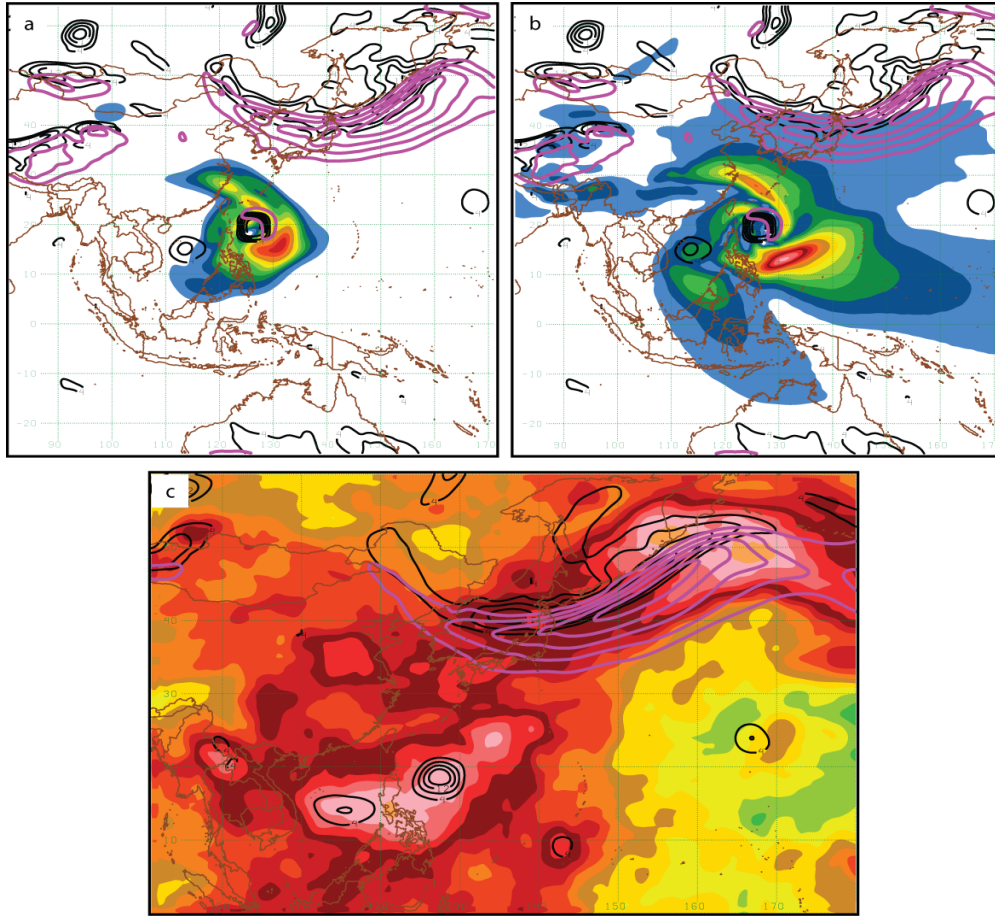


Figure 2. Targeting guidance for 48-hour forecast of Typhoon Jangmi. (a) Singular vectors, (b) ADSSV, and (c) ETKF signal variance (shaded). Vorticity (black contours every $4 \times 10^{-5} \text{ s}^{-1}$) and wind speed (magenta contours every 8 ms^{-1} starting at 24 ms^{-1}) is overlaid. Typhoon Jangmi appears in the center of plots (a) and (b), and southwest of the center in plot (c).

The principal effect of the perturbation in the $15^\circ \times 15^\circ$ verification region at 48 hours into the forecast is a displacement of the TC vortex to the west (east) for a positive (negative) initial condition vorticity perturbation (Fig. 3d), represented in the geopotential height field as a dipole with strong northward (southward) perturbation flow between the positive and negative lobes. Likewise, the perturbation kinetic energy is tied directly to the strong perturbation flow created by this dipole.

This illustrates the fact that the driving mechanism behind both of these guidance products is the ability of an initial condition perturbation to excite a track displacement from the unperturbed state. When the verification region is geographically constrained to be dominated by the (largely axisymmetric) flow of the TC, any small perturbation to the TC's final-time position from the center of the domain represents a very large departure to the mean flow (to which the axisymmetric component of the TC's own circulation can now significantly contribute) exciting the ADSSV, and the dipole structure of the perturbed field represents a tremendous amount of perturbation energy exciting the SV. Despite the large differences in methodology between these two guidance products, they appear to tend to converge onto the same target regions because they are both indirect measures of the same physical process: a small TC track displacement.

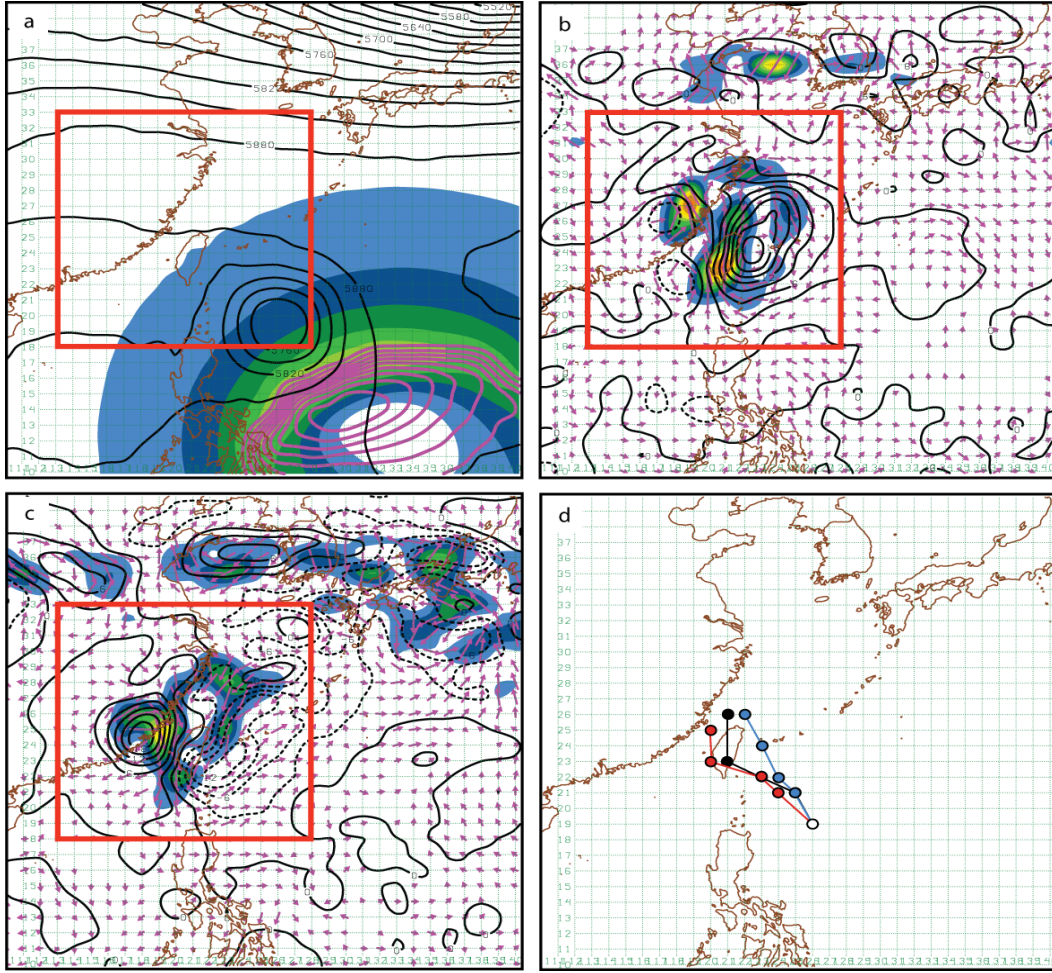


Figure 3. Perturbation experiment for Typhoon Jangmi. (a) Initial condition perturbation kinetic energy (shaded every $0.5 \text{ m}^2 \text{ s}^{-2}$), perturbation vorticity (magenta contours every $1.0 \times 10^{-1} \text{ s}^{-1}$), and geopotential height (black contours every 30 m). (b) Evolved perturbation kinetic energy (shaded every $10 \text{ m}^2 \text{ s}^{-2}$), perturbation geopotential height (black contours every 3 m, negative contours dashed), and perturbation winds, from a 48 hour forecast using a positive vorticity perturbation. (c) As per panel 2b, except evolved from a 48 hour forecast using a negative vorticity perturbation of the same magnitude. (d) The 48-hour tracks of the unperturbed forecast (black), forecast perturbed with positive vorticity (red), and forecast perturbed with negative vorticity (blue), and initial condition origin (white). The red box indicates the $15^\circ \times 15^\circ$ box over which SV and ADSSV metrics are measured.

This presents a problem for the ADSSV, which is engineered to (presumably) produce sensitivity of the TC *steering at the final time* to initial condition perturbations, while in-fact it seems to produce a sensitivity of the TC track displacement that has accumulated over the whole forecast trajectory. Likewise, the focus on TC track displacement in SV guidance implies that other physical processes of interest (e.g. sensitivity of the forecast intensity of the TC) may be systematically overlooked, because the way in which the SV metric is designed may define the effective growth-rate of a perturbation that principally *moves* the TC a small distance to be much higher than that of a perturbation that principally modulates the *intensity* of the TC. Therefore, if one were interested in targeting observations with the

explicit goal of improving TC intensity forecasting, it would seem that both of these targeting metrics might suffer large deficiencies.

When examining the ETKF signal variance, it is found that remote target areas appear downstream northeast of the TC in all four cases. The ADSSV found weak (though non-zero) sensitivity in these regions for two of the four cases (Nuri and Jangmi), while the SV analysis produces no downstream targets. It has been long thought that these remote downstream targets are merely a byproduct of the ETKF gravitating toward regions of large ensemble variance coupled to spurious long-distance correlations; however, the existence of these same downstream targets in the ADSSV opens the possibility for a real, physical mechanism in the model driving the identification of these targets.

As in the Jangmi experiment, a (positive) vorticity perturbation is inserted in the initial conditions of the Typhoon Nuri simulation (Fig. 4a), this time in the downstream region defined as a target by ADSSV (coincident with the ETKF signal variance). The goal is to determine how a downstream perturbation in a remote region northeast of the TC can have an impact on the TC. The vorticity perturbation creates a Rossby wave that propagates westward along the midlatitude potential vorticity waveguide (Fig. 4b); this wave forces poleward flow throughout the tropical basin to Nuri's east. This poleward flow modulates the strength of the subtropical ridge by increasing the anticyclonic vorticity via conservation of absolute vorticity, in this case increasing the anticyclonic circulation of the flow and raising geopotential heights in the ridge. By 48 hours into the simulation, the original wave feature has largely dissipated, but it leaves behind an enhanced anticyclonic flow in the subtropical ridge steering Nuri toward the northeast (Fig. 4c). This is consistent with a change in Nuri's motion to the northeast as a result of this perturbation (Fig. 4d).

This physical mechanism is subtle in that it is a secondary effect of the midlatitude Rossby wave and isn't an immediately obvious solution to how a perturbation to the northeast of the TC can affect the TC 48 hours later. Once again the effect appears to be largely focused on the track/steering of the TC rather than the intensity or structure of the TC vortex. The existence of such a physical mechanism explains why these downstream targets occasionally appear in the ADSSV guidance, though it is not clear what aspects of the flow are key to understanding which cases exhibit these downstream targets in ADSSV guidance and which do not. The absence of these downstream targets in SV guidance is likely due to the fact that the necessity to inject a large amount of energy into the initial conditions in the downstream region, coupled to the fact that most of that energy is "wasted" (as far as the SV energy norm is concerned) through the development of a Rossby wave that does not contribute to total perturbation energy in the verification region around the TC, means that these perturbations have a very low growth-rate and therefore are not typically represented in the leading singular vectors.

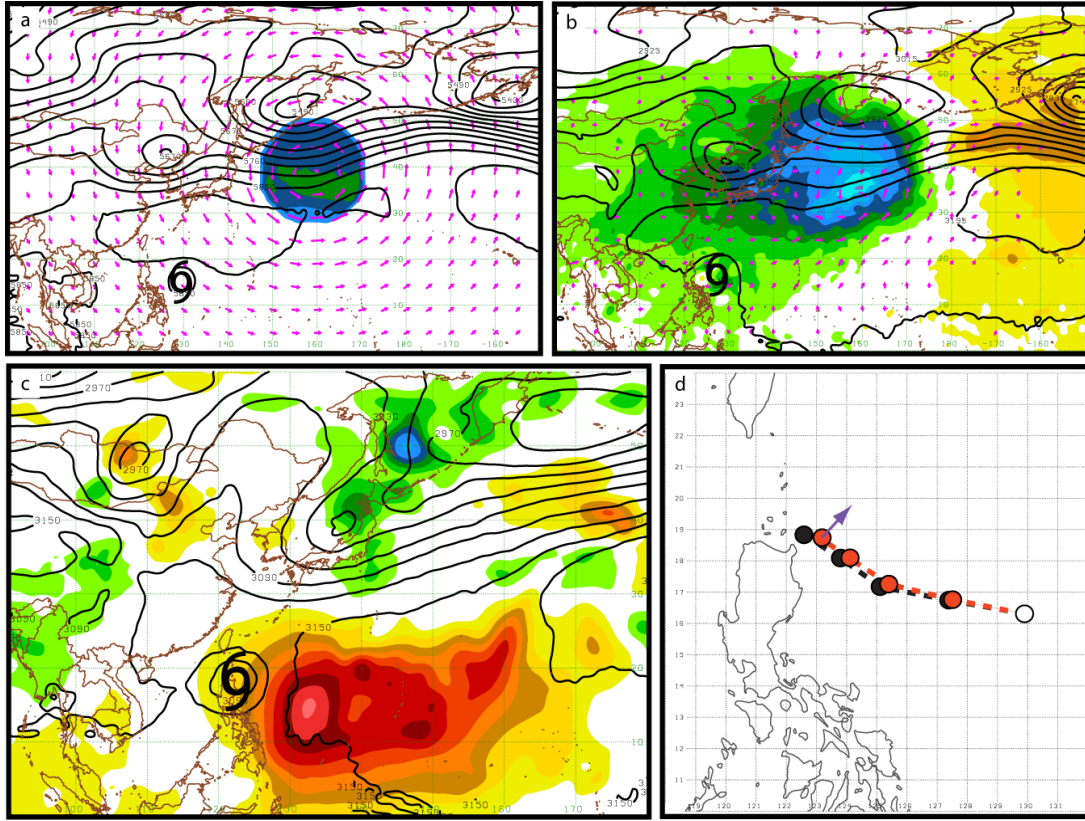


Figure 4. Downstream perturbation experiment for Typhoon Nuri. (a) Initial condition perturbation vorticity (shaded every $4 \times 10^{-6} \text{ s}^{-1}$), perturbation winds, and geopotential heights (black contours every 45 m) at 500 hPa. (b) Forecast of 12 hour geopotential heights (black contours every 45 m), perturbation heights (shaded every 2.5 m, cool colors negative), and perturbation winds at 700 hPa. (c) Verification time (48 hours) geopotential heights (black contours every 30 m) and perturbation “environmental wind” streamfunction (shaded every $2 \times 10^5 \text{ m}^2 \text{ s}^{-1}$, cool colors negative). (d) Track of unperturbed (black) and perturbed (red) Nuri simulation every 12 hours with initial condition origin (white). The purple arrow at 48-hour position represents the difference in observed motion between the perturbed and unperturbed simulations at this time.

The preponderance of these downstream targets in ETKF signal variance is likely due to the anomalously high ensemble variance in the downstream region in all four cases, suggesting a high level of uncertainty. The ETKF targets tend to gravitate toward these regions of high uncertainty even when the physical sensitivity is small (but non-zero); this is because the ETKF considers not only the sensitivity of the verification region around the TC to an initial condition perturbation, but also the likelihood that a new observation in that region is capable of producing that perturbation to the analysis. It is unclear if the existence of the TC in any contributes to enhanced downstream uncertainty in general, though studies have shown that TCs can significantly increase downstream uncertainty in cases of extratropical transition.

IMPACT/APPLICATIONS

A quantitative understanding of the influence of improved representations of the synoptic environment and outflow in the tropical cyclone will lead to new scientific conclusions on environmental interactions and modifications to tropical cyclone track and structure. The longer-term impact will be derived from the improved assimilation of targeted satellite wind observations in Navy (and other) models.

RELATED PROJECTS

This project is related to that funded by the TCS-08 grant N000140810250: “Using NOGAPS Singular Vectors to Diagnose Large-Scales on Tropical Cyclogenesis” (PI Majumdar; Co-PIs Peng and Reynolds of NRL Monterey). A supplement to the budget on that grant has enabled the further development of the WRF vortex initialization and inversion software for easy use by students and collaborators. This software is also being tested in the NOPP collaboration between Velden and Majumdar cited below.

This project is also related to that funded by NOPP grant N00014-10-1-0123: “Achieving Superior Tropical Cyclone Intensity Forecasts by Improving the Assimilation of High-Resolution Satellite Data into Mesoscale Prediction Models” (PIs Velden and Majumdar, Co-PIs Doyle and Hawkins of NRL-MRY).

PUBLICATIONS

Berger, H., Langland, R., Velden, C., Reynolds, C., and Pauley, P., 2011: Impact of enhanced satellite-derived atmospheric motion vector observations on numerical tropical cyclone track forecasts in the Western North Pacific during TPARC/TCS-08. *Journal of Applied Meteorology and Climatology*, **50**, Issue 11, 2309–2318.

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Hoover, B. T., C. S. Velden, and S. J. Majumdar, 2012: Physical Mechanisms Underlying Selected Adaptive Sampling Techniques for Tropical Cyclones. *Mon. Wea. Rev.* [submitted, refereed].

Reynolds, C., R. Langland, P. Pauley, and C. Velden, 2012: Tropical Cyclone Data Impact Studies: Influence of Model Bias and Synthetic Observations. *Mon. Wea. Rev.* [submitted, refereed].

HONORS/AWARDS/PRIZES

Co-PI Majumdar was appointed a Co-Chair of the American Meteorological Society’s annual conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS), held at the AMS Annual Meeting.

Co-PI Velden was awarded the 2012 University of Wisconsin Chancellor’s Award for Distinguished Research.